PRESICE ORBIT DETERMINATION FOR ADEOS-II

S. Nakamura(1), N. Kudo(1), Y. Yamamoto(2) and O. Montenbruck(3)

(1) Japan Aerospace Exploration Agency (JAXA), Consolidated Space Tracking and Data Acquisition Department, Flight Dynamics Team, 2-1-1 Sengen, Tsukuba, Ibaraki, 305-8505, Japan
e-mail: nakamura.shinichi@jaxa.jp, kudoh.nobuo@jaxa.jp
(2) Fujitsu Limited, 9-3 Nakase 1-chome, Mihama-ku, Chiba, Chiba, 261-8588, Japan
e-mail: yamamoto@ssd.ssg.fujitsu.com
(3) Deutschen Zentrum für Luft- und Raumfahrt (DLR), German Space Operations Center (GSOC), Oberpfaffenhofen 82234 Wessling Germany

ABSTRACT

We performed the precise orbit determination of ADEOS-II using single frequency GPS data and reviewed the results. JAXA precise orbit determination system is called “GUTS (Global and high accUracy Trajectory determination System)”. In the 18th ISSFD, we reported that the accuracy of precise orbit determination achieved about 51cm [1]. We compared the results with DLR’s orbit determination and SLR (Satellite Laser Ranging) data. The comparison showed that the DLR’s orbit determination was more precise than JAXA’s and there was a larger error in the along track component of GUTS results. We supposed that the difference in orbit determination accuracy between JAXA and DLR was partly due to the difference of the earth gravity potential model, and we upgraded the gravity potential model. We also corrected earth rotation parameter and redetermined the ADEOS-II orbit. The result was about 23cm. This result was precise enough for ADEOS-II, and comparable to DLR’s result.

1. INTRODUCTION

In September 2000, JAXA constructed its precise orbit determination system called “GUTS (Global and high accUracy Trajectory determination System)”. JAXA continually performs the precise orbit determination experiment for ADEOS-II using GUTS. We will report the result of the precise orbit determination for ADEOS-II, which was launched by H-2A launch vehicle in December, 2002.

2. OVERVIEW OF GUTS SYSTEM

The system overview of GUTS is shown in Fig1.
GUTS consists of 7 subsystems: GPS ground station subsystem, GPS ground station control subsystem, SLR ground station subsystem, SLR ground station control subsystem, Master Control and Operation Planning subsystem (COPs), Orbit Determination subsystem and Data Transfer subsystem.
In this section, we outline these subsystems and there functions.

2.1 GPS ground stations subsystem

GUTS has 5 GPS ground stations. (2 sites are located in Japan and 3 sites are located overseas.)
These GPS antennas are about 2.5 meter tall with a dome to protect antenna from the rain and snow and with a plate to detect reflection. GPS stations can receive L1 and L2 carrier phase signals from GPS satellites.
These GPS ground stations receive GPS data all of the day, and send these data to GPS station control subsystem.

2.2 GPS Station Control subsystem

GPS station control subsystem controls remote GPS ground stations subsystem. This system collects GPS raw data from GPS ground stations and converts them to RINEX format. RINEX data and raw data are sent daily to and stored in the Data archive (a part of Orbit Determination subsystem)

2.3 SLR ground station subsystem

SLR ground station subsystem comprises SLR station. GUTS uses not only GPS data also SLR data. JAXA has a SLR station in Tanegashima and operates this station using SLR Station Control subsystem from Tsukuba Space Center by remote control. We also gather SLR data from CDDIS (Crustal Data Information System) data server and SLR stations in Japan (NICT/Koganei and Shimosato.).

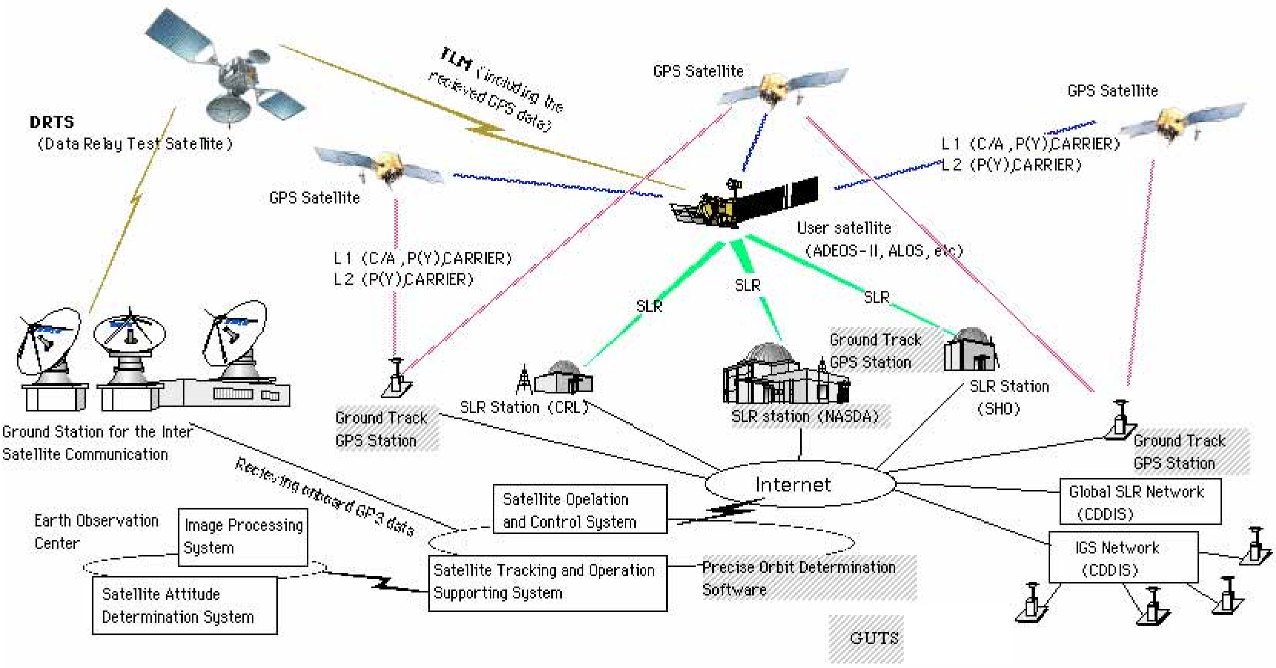

Fig1. Overview of GUTS system

2.4 SLR Station Control subsystem

SLR station control subsystem is used to operate the SLR station. This subsystem generates satellite-tracking information of telescope in TIRV (Tuned InterRange Vector) format. SLR station control subsystem receives operation plan of SLR station from COPs and operates SLR station according to COPs' plan. SLR data is sent to the Data archive after the pass operation and used for orbit determination. SLR data obtained by JAXA SLR station is sent to CDDIS data server, which are utilized for geodetic science.

2.5 Master Control and Operation Planning subsystem

Master Control and Operation Planning subsystem (COPs) controls all of the GUTS operations. Operators input operation plan into COPs and manage GUTS operation. COPs schedules the total operation of GUTS (Orbit Determination/ GPS stations/ Data transfer…) and directs the operation of each subsystem.
An Operation plan consists of some tasks. And each subsystem carries out operation based on the operation plan received from COPs. When a subsystem has completed its operation, it sends the result of the solution to COPs.

2.6 Precise Orbit Determination subsystem

Precise Orbit determination subsystem is divided into two parts. One is Orbit determination calculation part, the other is Data archive part.
Orbit determination calculation part is the main part of GUTS. This part performs precise orbit determination using GPS and/or SLR data and evaluates orbit accuracy. Data archive part accumulates and manages all of the data used for orbit determination.
Data archive part collects

- -Onboard GPSR data from the Satellite Operation and Control System
- -On-orbit satellite condition (on-board attitude, temperature data and so on.)
- -GPS and SLR data from each ground site(GPS and SLR data from IGS and CDDIS global sites)
- -Astronomical data (earth rotation parameters, solar flux and geomagnetic, etc.)

We perform precise orbit determination by using a high precise observation model compliant with the IERS Standard [2, 3] together with the satellite motion model.

Details of GUTS, such as system constitution, method of processing data, and various models employed in the system, were reported by Maeda, et al [4].

2.7 Data Transfer subsystem

Data transfer subsystem is the interface point between GUTS and other organizations. This system gathers solar flux data, polar motion data etc, ground GPS data (from IGS), global SLR data (from CDDIS), and other necessary data for orbit determination.
Another important function of this subsystem is to deliver information generated by GUTS, such as precise orbit ephemeris, SLR prediction data (TIRV), SLR data evaluation report, SLR/GPS data obtained by JAXA

stations and. These data are transmitted via INTERNET (ftp/SMTP).

3. OVERVIEW OF ADEOS-II PRECISE ORBIT DETERMINATION

ADEOS-II was developed to observe and investigate global climate change such as global heating. This satellite was launched in December 2002 and its operation was terminated due to the trouble of power supply in October 2003. Though the operation life was short, sufficient amount of data from an onboard GPS receiver was accumulated.

Fig.2 ADEOS-II

Because the GPS receiver of ADEOS-II is a single frequency type, the ionosphere correction is imperfect. And the quality of the data was moderate (not excellent) due to frequent cycle slips. Because the error of the ionosphere correction is about a few meters, our goal is to achieve the accuracy of the orbit determination within a few meters

In the 18th ISSFD, we reported that the accuracy of precise orbit determination achieved about 51cm [1]. Table1 shows the results of the orbit determination that we reported in the 18th ISSFD.

In evaluating the orbit determination accuracy, we used overlap method and orbit determination residual (O-C) method.

Table 1. Summary of JAXA precise orbit determination result (unit: m)

	Radial Direction	Cross Track Direction	Along Track Direction	Difference (3D-RMS)
Results	-0.02±0.15	-0.03±0.22	-0.24±0.36	0.51

4. COMPARISON OF JAXA'S ORBIT DETERMINATION WITH DLR'S

We carried out a cross validation of orbit accuracy for ADEOS-II as a cooperative research with the Germany space agency, or DLR [5,6].

JAXA and DLR independently analyzed the same onboard GPS data using each precise orbit determination system and compared the result to verify the reliability for ADEOS-II's orbit. In order to remove the effect of the ionospheric delay, we used GRAPHIC(=(C1+L1)/2, where L1 and C1 are the carrier phase and pseudorange data, respectively). In carrier phase and pseudorange, the effects of ionospheric delay were of the same magnitude, but of the opposite sign. So we could perform the ionospheric correction by combining these data linearly. DLR's orbit determination system, which is called GHOST[7,8], achieved about 27cm of orbit determination accuracy for ADEOS-II. Table 2 shows the summary of the result. GHOST has proven its accuracy in the past precise orbit determination for a lot of satellites. Fig. 3 and Table 3 show the result of the cross validation. We found that the radial direction and cross track direction agreed, however, a large difference existed in the along track direction between JAXA's and DLR's orbit determinations.

Table 2. Summary of DLR precise orbit determination result (unit: m)

	Radial Direction	Cross Track Direction	Along Track Direction	Difference (3D-RMS)
Results	-0.00±0.07	0.02±0.19	-0.02±0.17	0.27

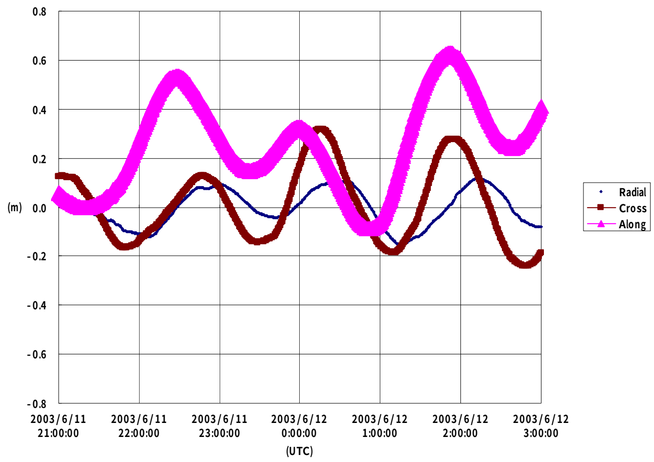

Fig. 3 Each component of the difference of the orbit determination between JAXA and DLR ; The horizontal axis shows the time, and the vertical axis shows the difference.

(Fine line : Radial Direction)

(Middle line : Cross Track Direction)

(Bold line : Along Track Direction)

Table 3. The difference of the orbit determination between JAXA and DLR (unit: m)

	Radial Direction	Cross Track Direction	Along Track Direction	Difference (3D-RMS)
Results	0.01±0.10	0.01±0.18	0.31±0.32	0.50

5. COMPARISON WITH SLR DATA

We compared these data with SLR data to evaluate the accuracy of GPS-based orbit determination. We calculated O-C(Observation(=SLR)-Calculation (GPS orbit determination results)) for each (JAXA and DLR) GPS orbit determination results. Originally we planned to perform precise orbit determination for ADEOS-II by using enough SLR data. But laser tracking was restricted because of the interference with onboard observation sensor. So we didn't have enough SLR data. We calculated O-C instead of comparing the orbit determinations. SLR is independent of GPS data and useful as an independent verification although our SLR data was little. The result is shown in Fig. 4.

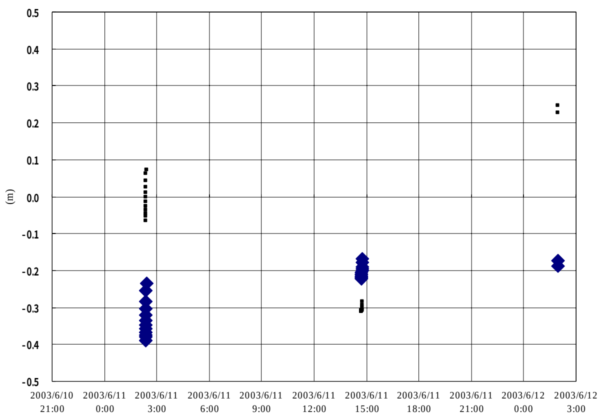

Fig.4 The difference with SLR data ; The horizontal axis shows the time, and the vertical axis shows the difference.

(Large point : The difference between SLR and JAXA's orbit determination)

(Small point : The difference between SLR and DLR's orbit determination)

Table 4. The difference with SLR data (unit: m)

	Average	RMS
DLR	-0.12	0.22
JAXA GUTS	-0.26	0.27

As a result of comparing SLR with DLR's and JAXA's orbits determinations, DLR's orbit agreed more with SLR data than JAXA's orbit. So we decided to investigate causes of the error and to improve GUTS.

6. INVESTIGATION OF CAUSES OF THE ERROR

We focused our analysis on the investigation of causes of the error. There were some differences between JAXA GUTS and DLR GHOST in models and techniques of the orbit determination. At first we focused attention on the difference of the geopotential model. DLR used GGM-01 geopotential model (resolution : 120*120) whereas JAXA used JGM-3[9] geopotential model (resolution : 70*70). GGM-01 was newer and more precise than JGM-3. ADEOS-II was a low earth orbit satellite and it was likely to be influenced by gravity. So we thought that the error of the geopotential might be due to the difference of the orbit determination. And we changed the geopotential model from JGM-3 to GGM-02C(resolution : 200*200).

Table 5. shows the results of the orbit determination after we changed the geopotential model. 3D-RMS was improved slightly (from 50cm to 43cm), but there was not so much improvement as we expected.

By using GGM-02C, we think that we removed the error resulting from the geopotential model in principle because GGM-02c is derived from the precise orbit determination of GRACE. This means that geopotential model can be excluded from possible causes of the error. Possible causes of the error (except the earth rotation parameter) are atmospheric drag, ionospheric delay, tropospheric correction and dynamics model and so on.

Table 5. The difference of the orbit determination between JAXA and DLR (unit: m)

GUTS Earth Gravity	Radial Direction	Cross Track Direction	Along Track Direction	Difference (3D-RMS)
JGM-3 (Before)	0.01±0.10	0.01±0.18	0.31±0.32	0.50
GGM-02C (After)	0.01±0.08	0.00±0.13	0.31±0.26	0.43

Then we investigated database setting values such as earth rotation parameter and astronomical constant in GUTS. In the process of the investigation, we found that the earth rotation parameter was wrong. So we corrected the earth rotation parameter in GUTS and performed the orbit determination again. The results are shown in Fig. 5 and Fig. 6 and Table 6.

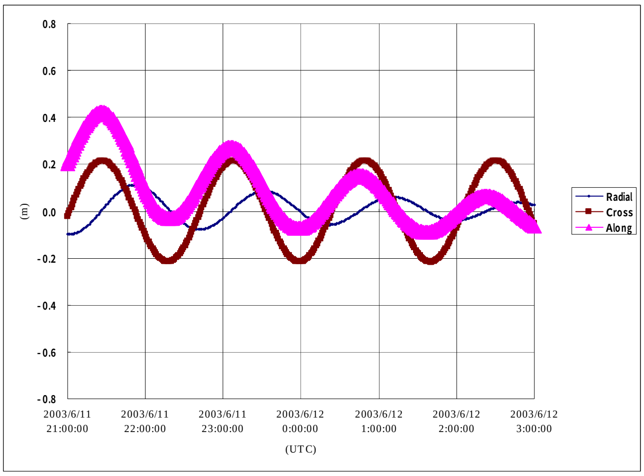

Fig. 5 Accuracy of JAXA precise orbit determination by overlap method; each component of the difference of orbital position. The horizontal axis shows the time, and the vertical axis shows the difference.

(Fine line : Radial Direction)

(Middle line : Cross Track Direction)

(Bold line : Along Track Direction)

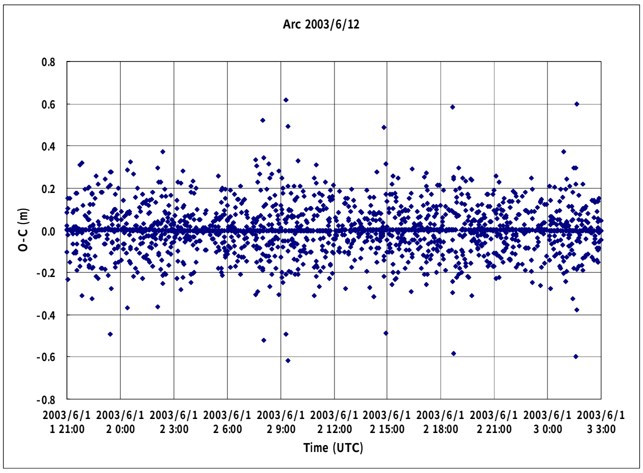

Fig. 6 The residuals between JAXA determined ADEOS-II orbit and GPS data; The horizontal axis shows the time, and the vertical axis shows the orbit determination residual.

Table 6. Summary of final OD accuracy (unit cm)

	Radial Direction	Cross Track Direction	Along Track Direction	Difference (3D-RMS)
Results	0.01±0.05	0.02±0.15	0.09±0.14	0.23

According to the results, the accuracy of GUTS was improved. We achieved the orbit determination accuracy of about 23cm. We think that this accuracy is precise enough for ADEOS-II, whose altitude is 800km, with single frequency type GPS receiver.

7. CONCLUSION

By changing the geopotential model, the accuracy of the orbit determination was improved, though not significantly. We could exclude the geopotential model from possible cause of the error. By clearing up the cause of the error, we found that the earth rotation parameter was wrong. After correcting the earth rotation parameter, we confirmed that it is possible to achieve an accuracy of about 23cm (RMS). The result reached our goal of the accuracy (within a few meters) and this accuracy is precise enough for ADEOS-II, whose altitude is 800km, with 1 frequency type GPS receiver.

JAXA launched ALOS (Advanced Land Observing Satellite) in this January. This satellite is also an earth observing satellite, and precise orbit determination is very important for the mission. Now we are analyzing the GPS data, and we will perform SLR tracking in the near future. We can utilize this experience in the analysis for ALOS.

References

[1] S. Nakamura, et al., “Results of The Precise Orbit Determination Experiment with ADEOS- II,” 18th International Symposium on Space Flight Dynamics Proceedings, pp.163-168, Munich, Germany, 2004

[2] Maeda M., et al., “NASDA Precise Orbit Determination Experiment of ADEOS-II,” 17th International Symposium on Space Flight Dynamics Proceedings, Vol2, pp.174-186, Moscow, Russia, 2003

[3] Dennis D. M. and Gerard P, IERS Technical Note32, IERS Conventions, 1996

[4] Dennis D. M., IERS Technical Note21, IERS Conventions, 2003

[5] O. Montenbruck, “ADEOS-II Orbit Determination using Single-Frequency GPS Measurements,” DLR-GSOC TN 05-01, 2005

[6] E. Gill, O. Montenbruck, “Comparison of GPS-Based Orbit Determination Strategies,” 18th International Symposium on Space Flight Dynamics Proceedings, pp.169-174, Munich, Germany, 2004

[7] O. Montenbruck, T. van Helleputte, R. Kroes, E. Gill “Reduced Dynamic Orbit Determination using GPS Code and Carrier Measurements,” accepted for Aerospace Science and Tecnology, 2005

[8] O. Montenbruck, E. Gill, R. Kroes "Rapid Orbit Determination of LEO Satellites using IGS clock and Ephemeris Products, " submitted GPS solutions, 2004

[9] B.D. Tapley, M.M. Watkins, J.C. Ries, G.W. Davis, R.J. Eanes, S.R. Poole, H.J. Rim, B.E. Shutz, C.K. Shum, R.S. Nerem, F.J. Lerch, J.A. Marshall, S.M. Klosko, N.K. Pavlis, "The JGM-3 gravity model,"